



The Cluster Implant Source

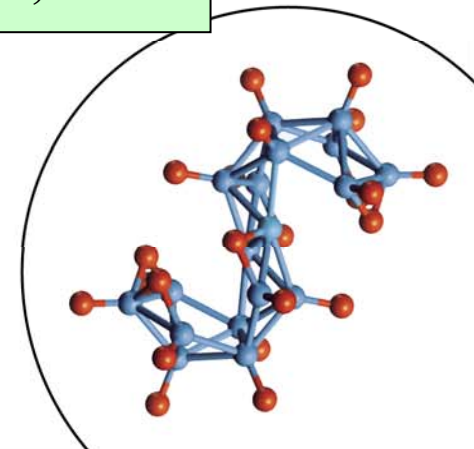
Optimization of Si:C stress retention and junction quality with ClusterCarbon implantation

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KYOTO, JAPAN



Plan of the talk

- Advantages with ClusterCarbon approach for Si:C formation
- Self-amorphization and recrystallization – background summary for ClusterCarbon
- Implant and experimental scheme :
- Optimization of Dose and Energy for Phos implant -
Rs, SIMS, $[C]_{\text{subs}}$
- Summary

Si:C Layer Formation :

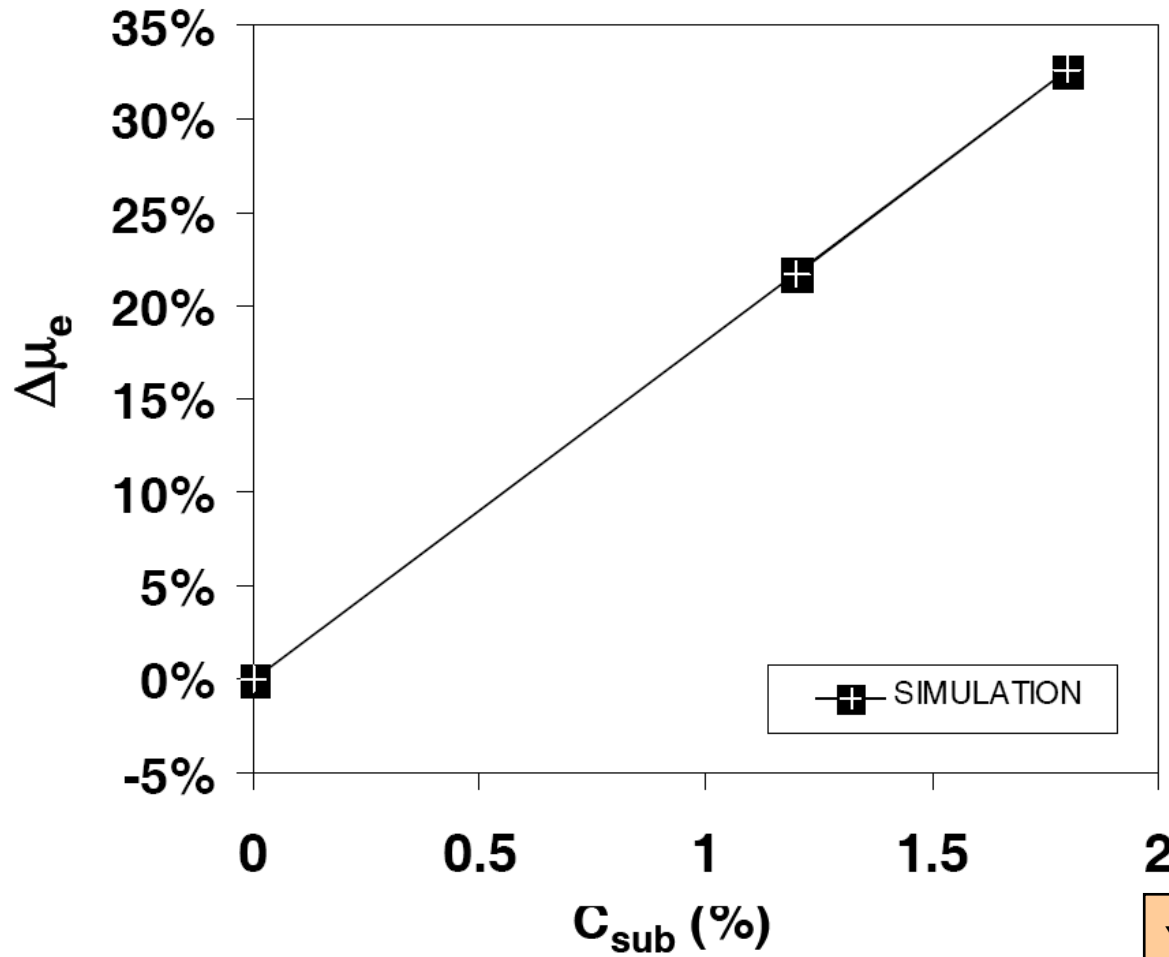
ClusterCarbon™ implant approach

Advantages :

$[C]_{\text{sub}} > 2\%$ with ms anneal

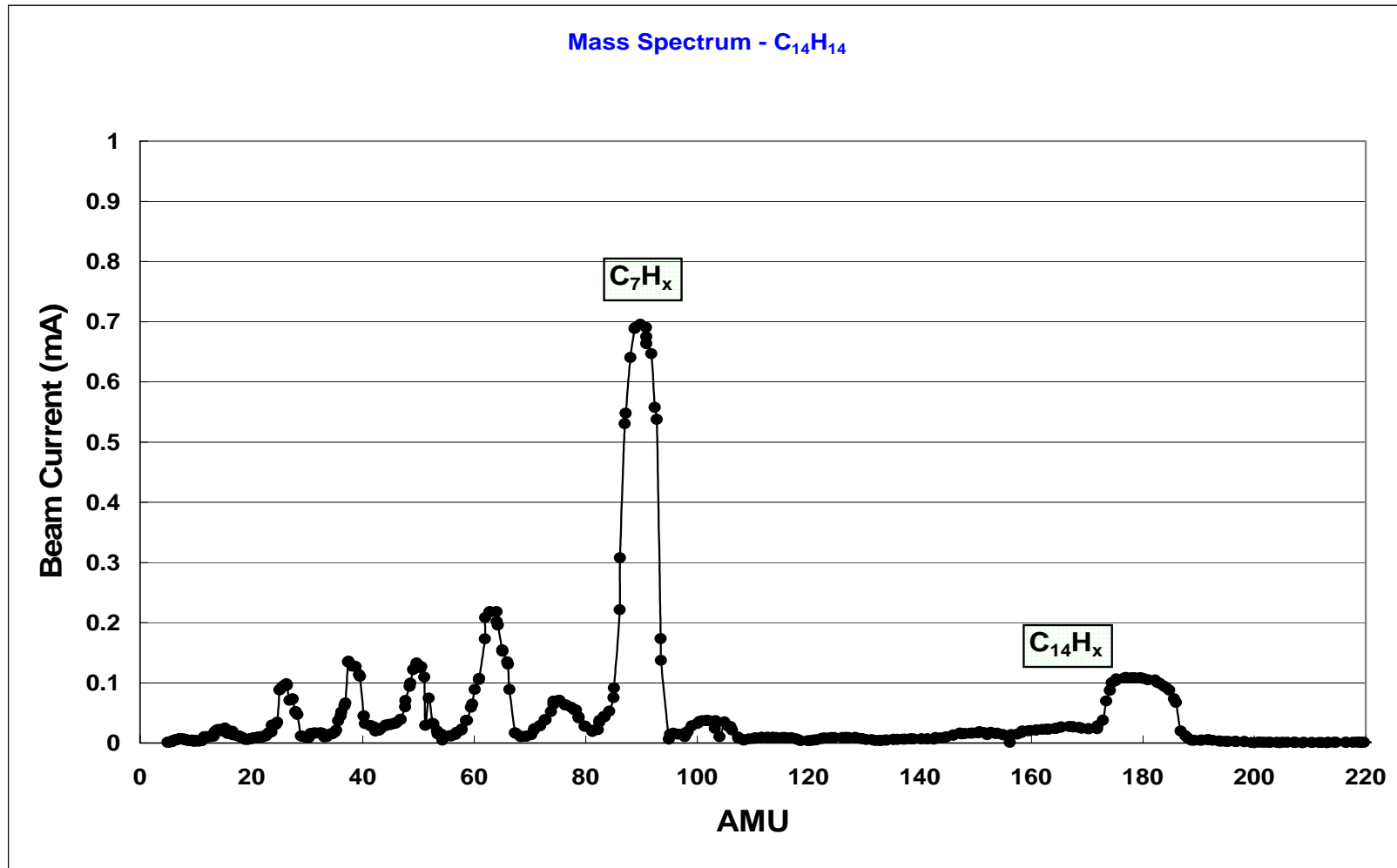
- Self-amorphization with molecular implants
- Elimination of extra PAI-implant
- By suitable process sequence, elimination of end of range damage and better recrystallization
- Higher $[C]_{\text{subs}}$ with millisecond anneal
- Low Rs and better dopant activation
- Better throughput

Mobility Enhancement vs % of $[C]_{\text{subs}}$



Y. Cho et al, EMRS, 2008

Mass Spectrum of $C_{14}H_{14}$ molecule



Recrystallization - ClusterCarbon

X-TEM C_{16} (3keV) + B_{18} (0.5keV) @1e15 atoms/cm²

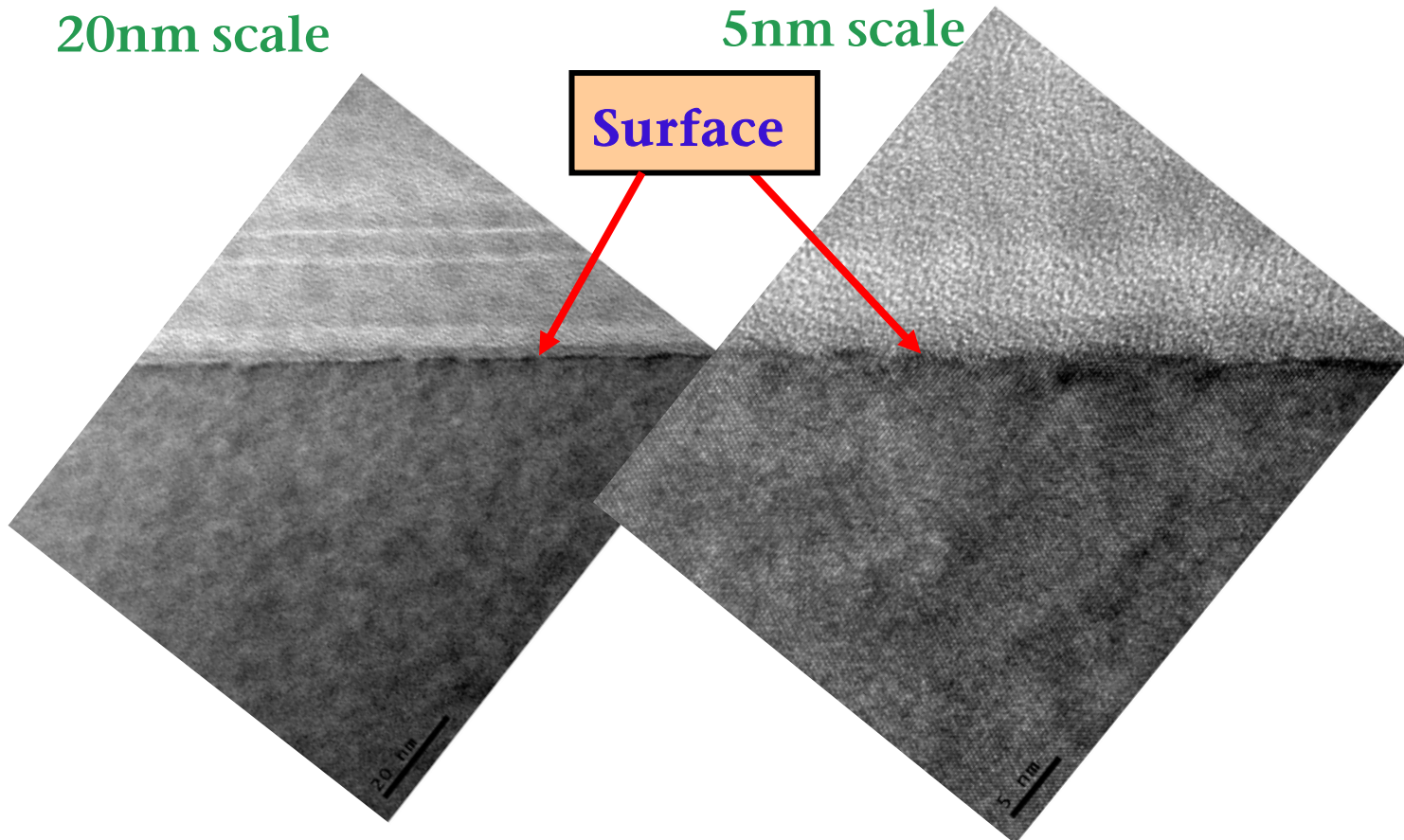
950°C , 5 sec – annealed

NO EOR DAMAGE

20nm scale

5nm scale

Surface



▪ No EOR damage is seen with TEM for 950°C 5 sec anneal

XTEM

1.5% atomic carbon

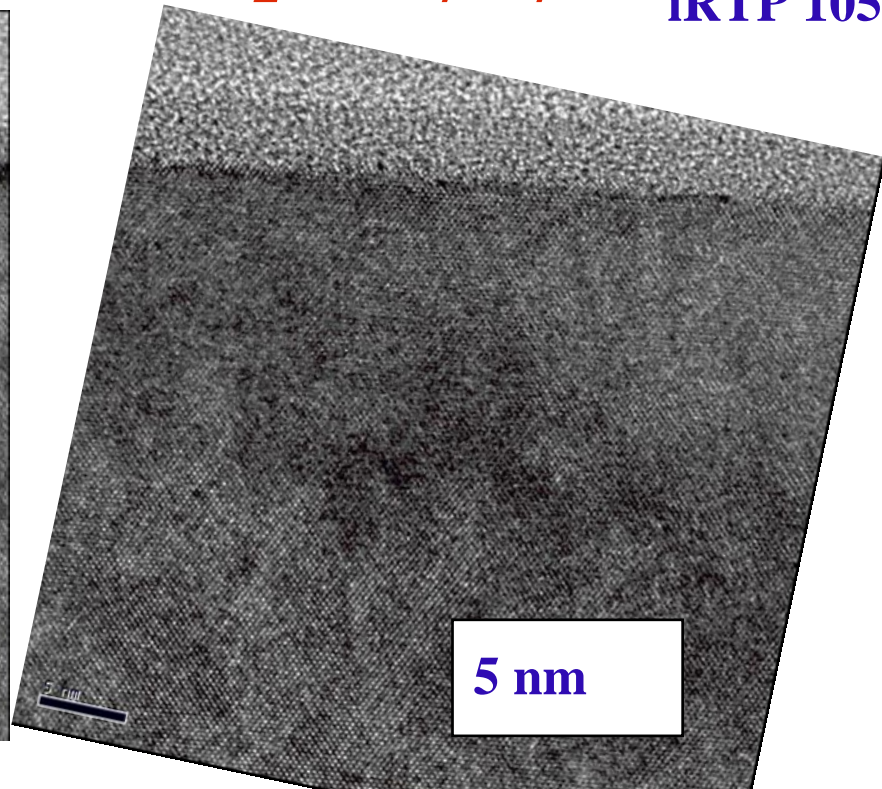
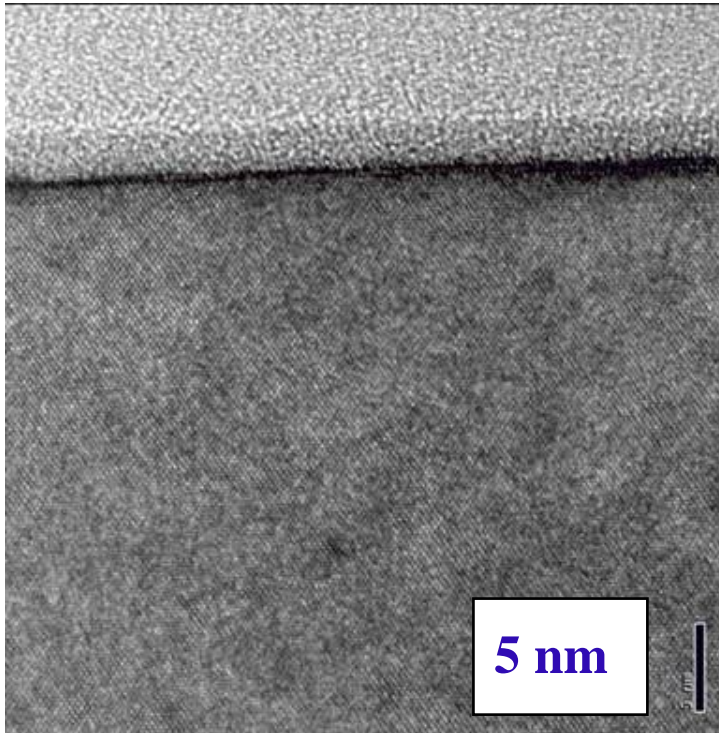
C_7H_7 vs $(P_2 + C_7H_7)$

C_7H_7

fRTP 1200°C +
iRTP 1050°C

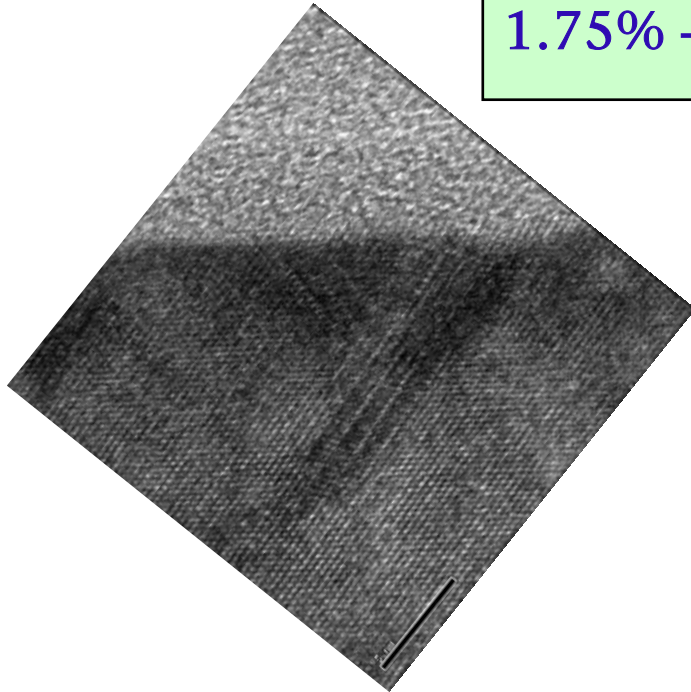
$P_2 + C_7H_7$

fRTP 1200°C +
iRTP 1050°C



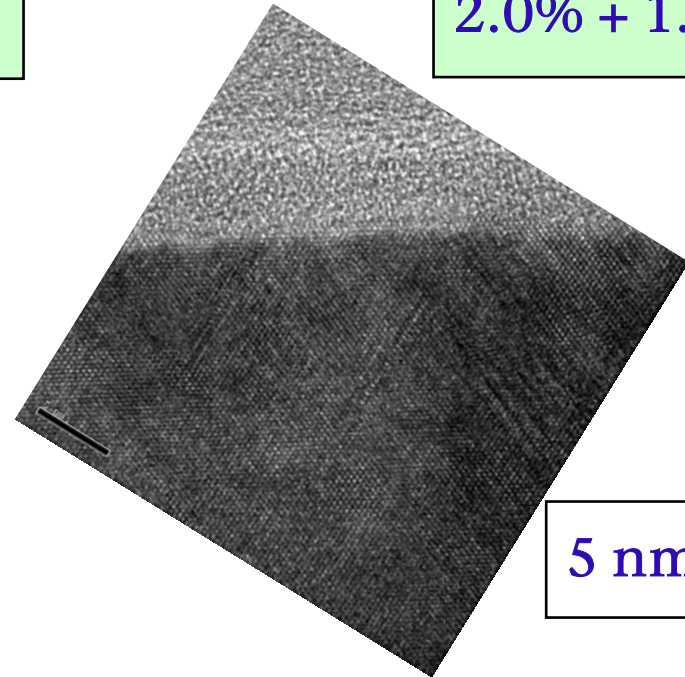
No regrowth defects after iRTP 1050°C for both C_7 and P_2+C_7 cases.

$P_2 + C_7H_7$ XTEM
(iRTP 1050°C + fRTP 1250°C)



1.75% + 1.5%

**Many stacking faults
with a couple of
EOR loops**



2.0% + 1.5%

5 nm

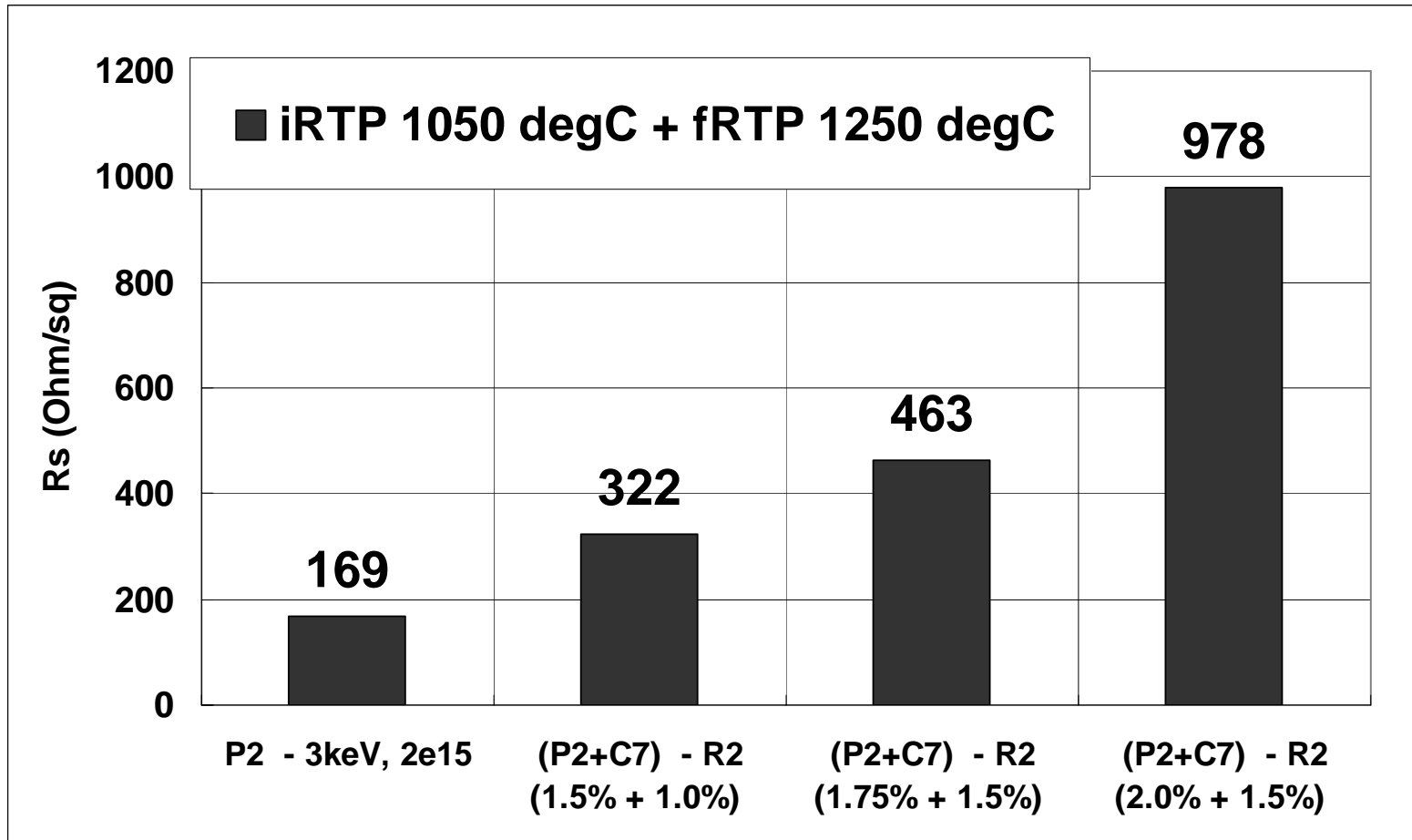
**Very many stacking
faults with a couple
of EOR loops**

- ❖ Trade off between R_s and $[C]_{\text{subs}}$
- ❖ Anneal scheme dependence for $[C]_{\text{subs}}$
- ❖ Fraction of carbon in amorphous layer vs $[C]_{\text{subs}}$



Rs results

(iRTP 1050°C + fRTP 1200°C)

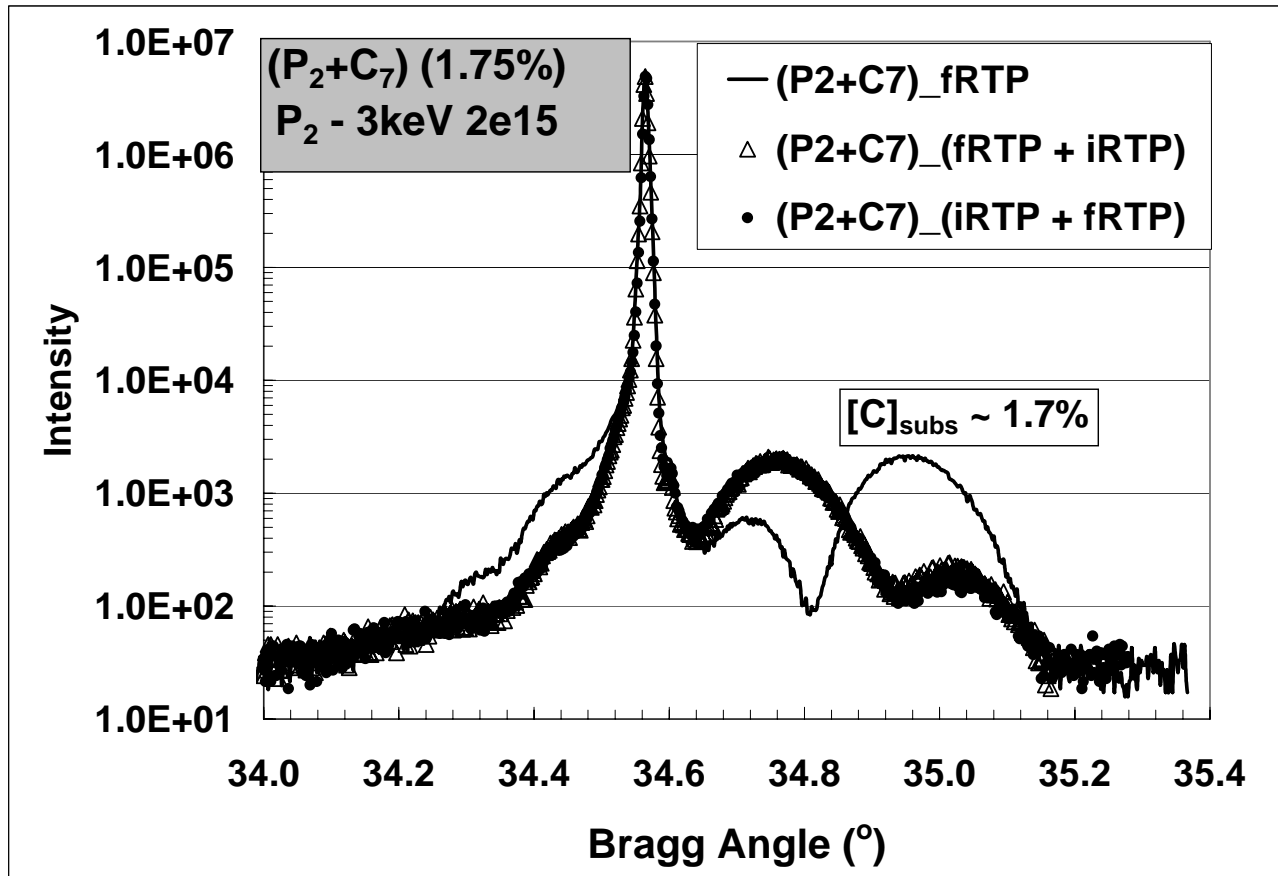


Dramatic increase in Rs beyond 1.75% atomic carbon. Precipitation of carbon beyond 1.70%



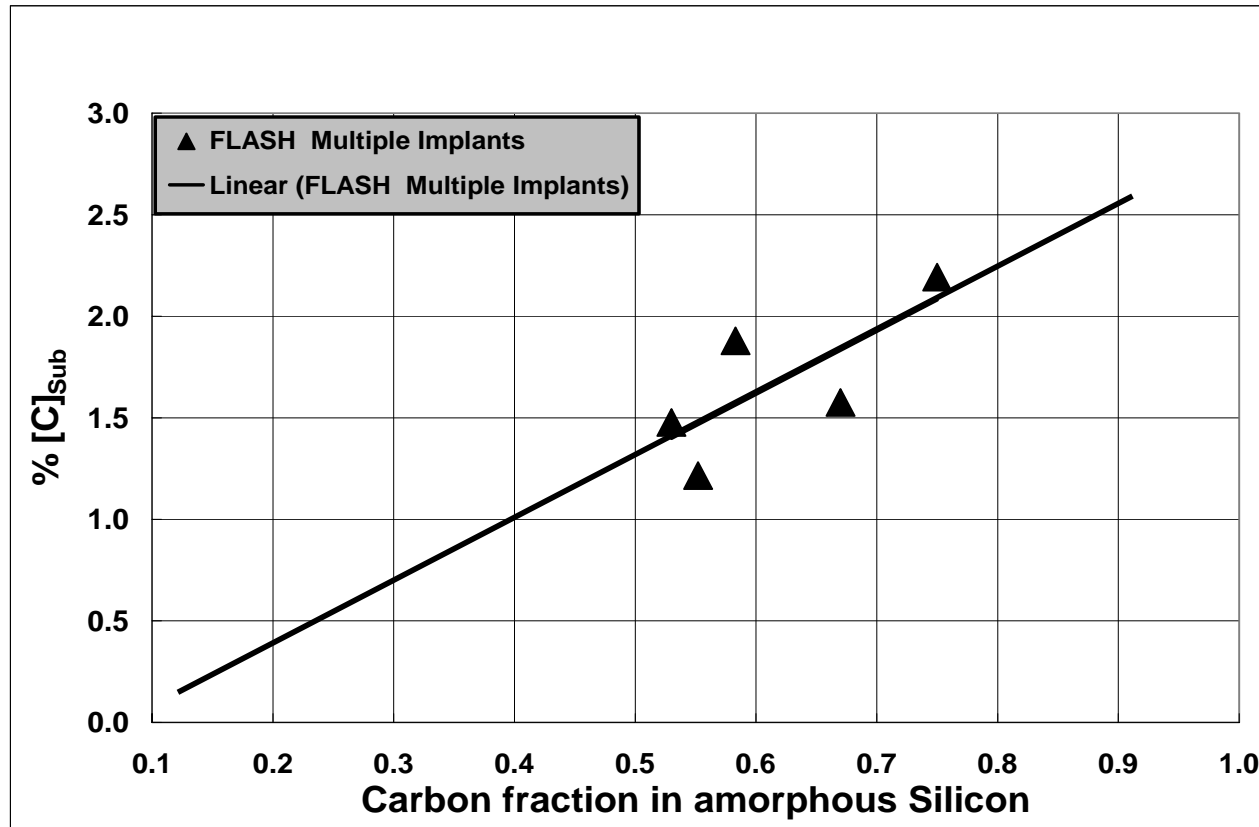
(iRTP 1200°C + iRTP 1050°C)

Rs results



No difference in % of [C]_{subs} with change in anneal sequence.

α -Si vs $[C]_{\text{subs}}$ - Flash anneal study

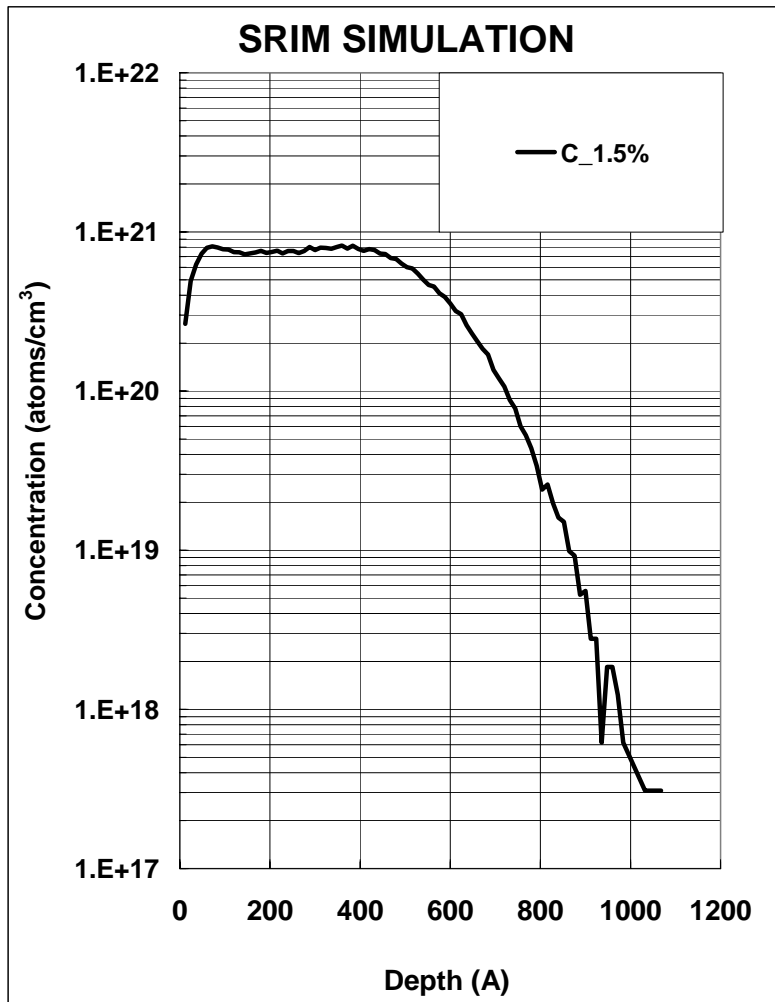


Higher fraction of carbon in amorphous layer thickness leads to high $\%[C]_{\text{subs}}$

What we learned so far?

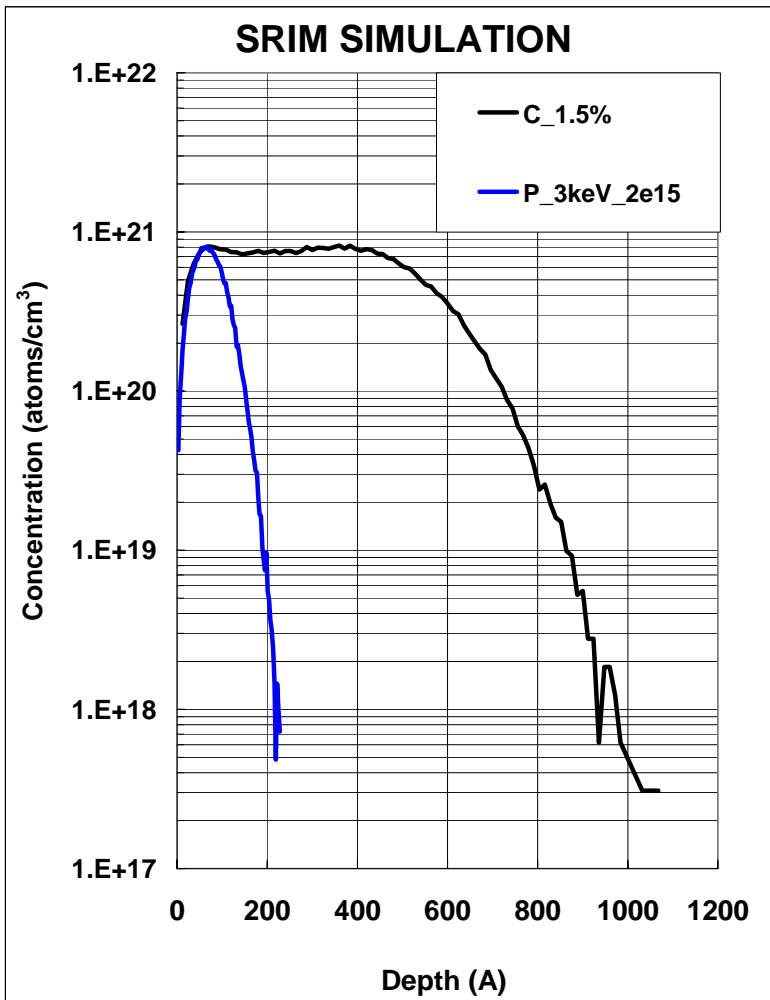
- Amorphous layer thickness is critical to get large strained layer
- Increase in R_s is dramatic beyond 1.70% atomic carbon
- Observation of stacking faults beyond 1.50% atomic carbon
- No difference in $[C]_{\text{subs}}$ if the anneal sequence is interchanged
(flash + spike) or (spike + flash)

Implant and experimental scheme : P + C₇H₇



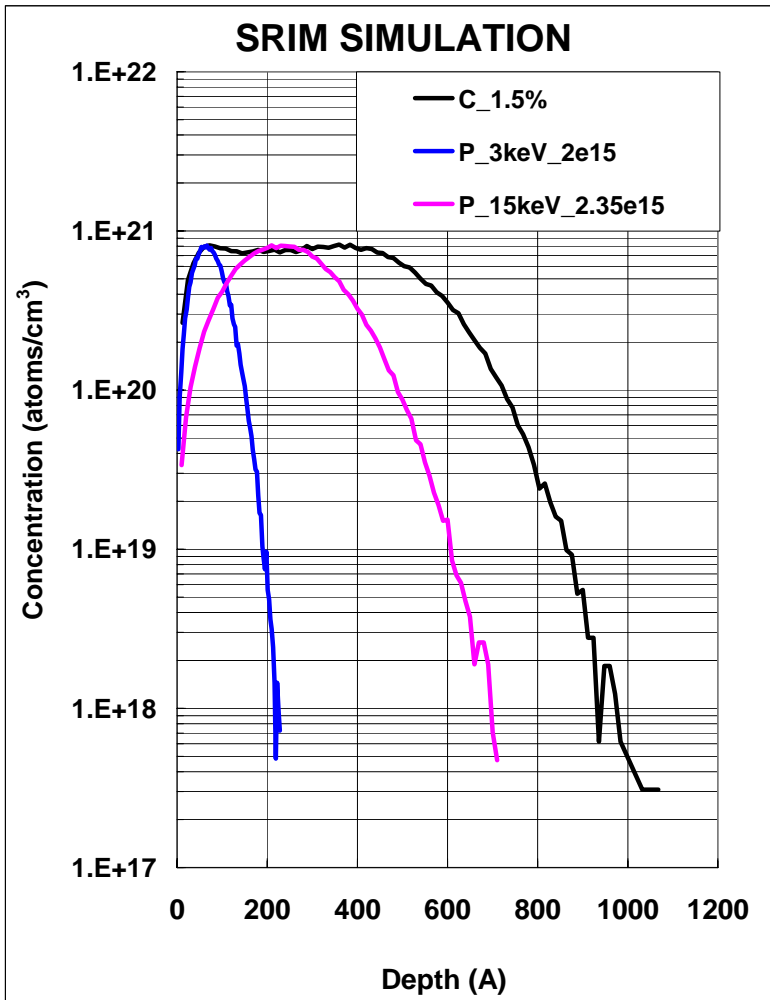
- 1) Flat carbon profile around 1.5% atomic carbon

Implant and experimental scheme : P + C₇H₇



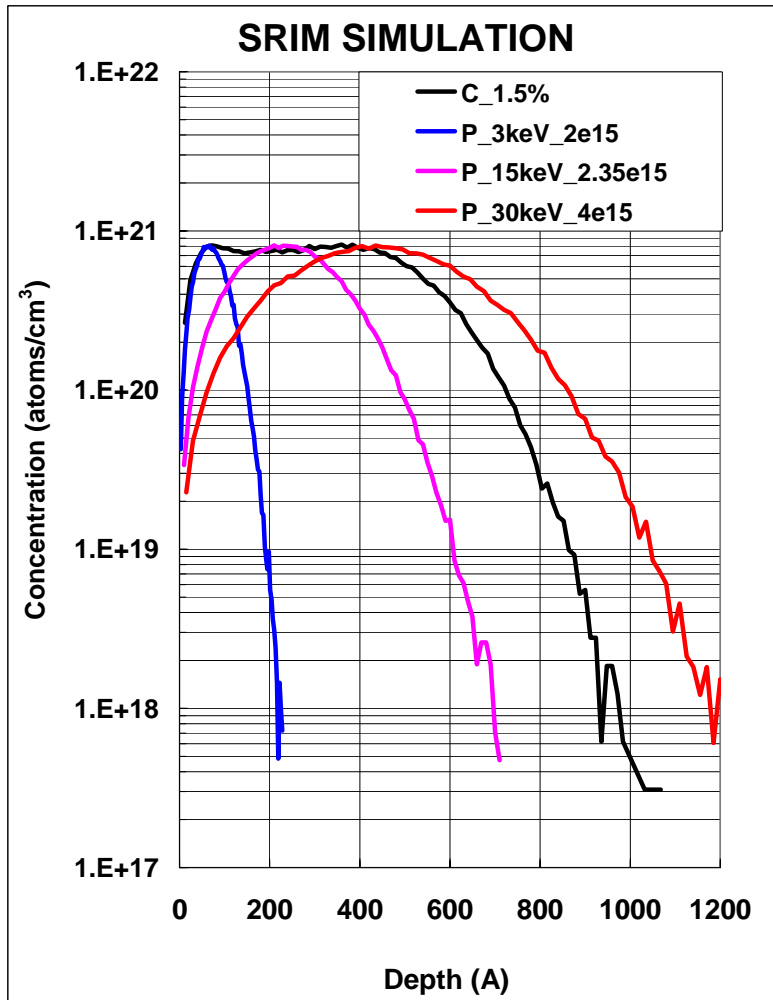
- 1) Flat carbon profile around 1.5% atomic carbon
- 2) Phos energy and dose in such a way the position of the P dopant fall at the **surface**, in the middle and at the end of the C profile

Implant and experimental scheme : P + C₇H₇



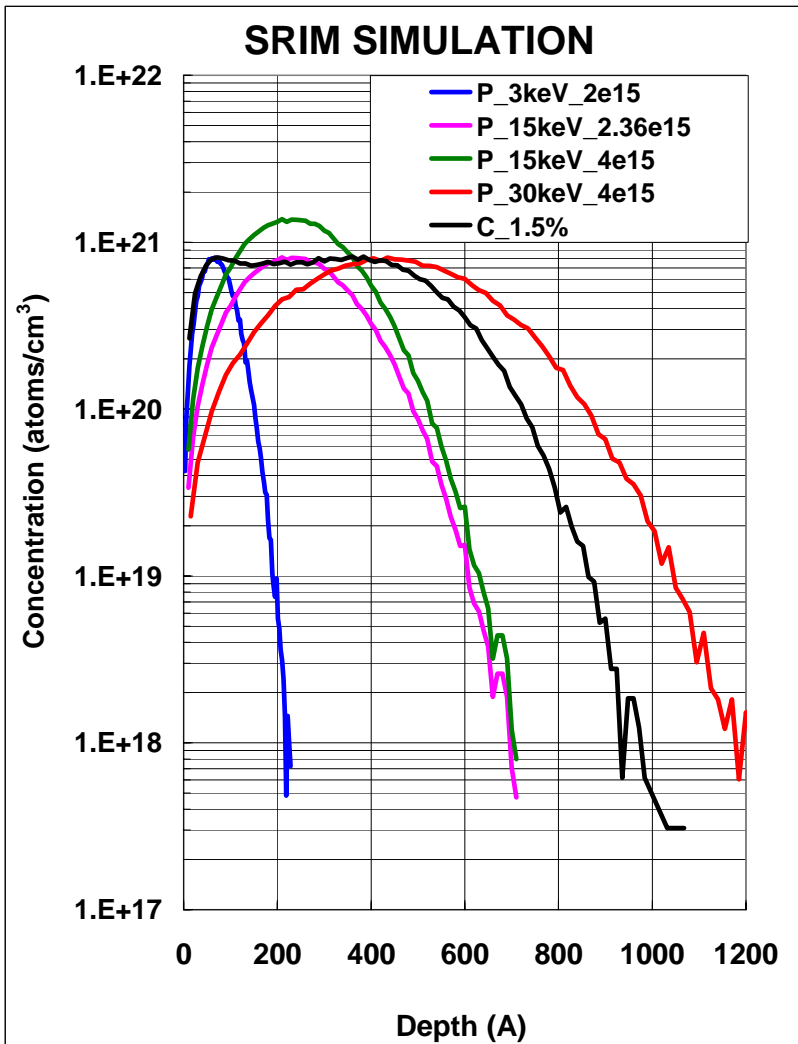
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Implant and experimental scheme : P + C₇H₇



- 1) Flat carbon profile around 1.5% atomic carbon
- 2) Phos energy and dose in such a way the position of the P dopant fall at the surface, in the middle and at the **end** of the C profile
- 3) Various peak conc. Of Phos

Implant and experimental scheme : P + C₇H₇



- 1) Flat carbon profile around 1.5% atomic carbon
- 2) Phos energy and dose in such a way the position of the P dopant fall at the surface, in the middle and at the end of the C profile
- 3) Various peak conc. of Phos
- 4) Flash anneal, flash + spike, spike
- 5) R_s, SIMS, HRXRD, XTEM

Rs - Energy and Dose Variations : C₇ + Phos

Anneal dependence

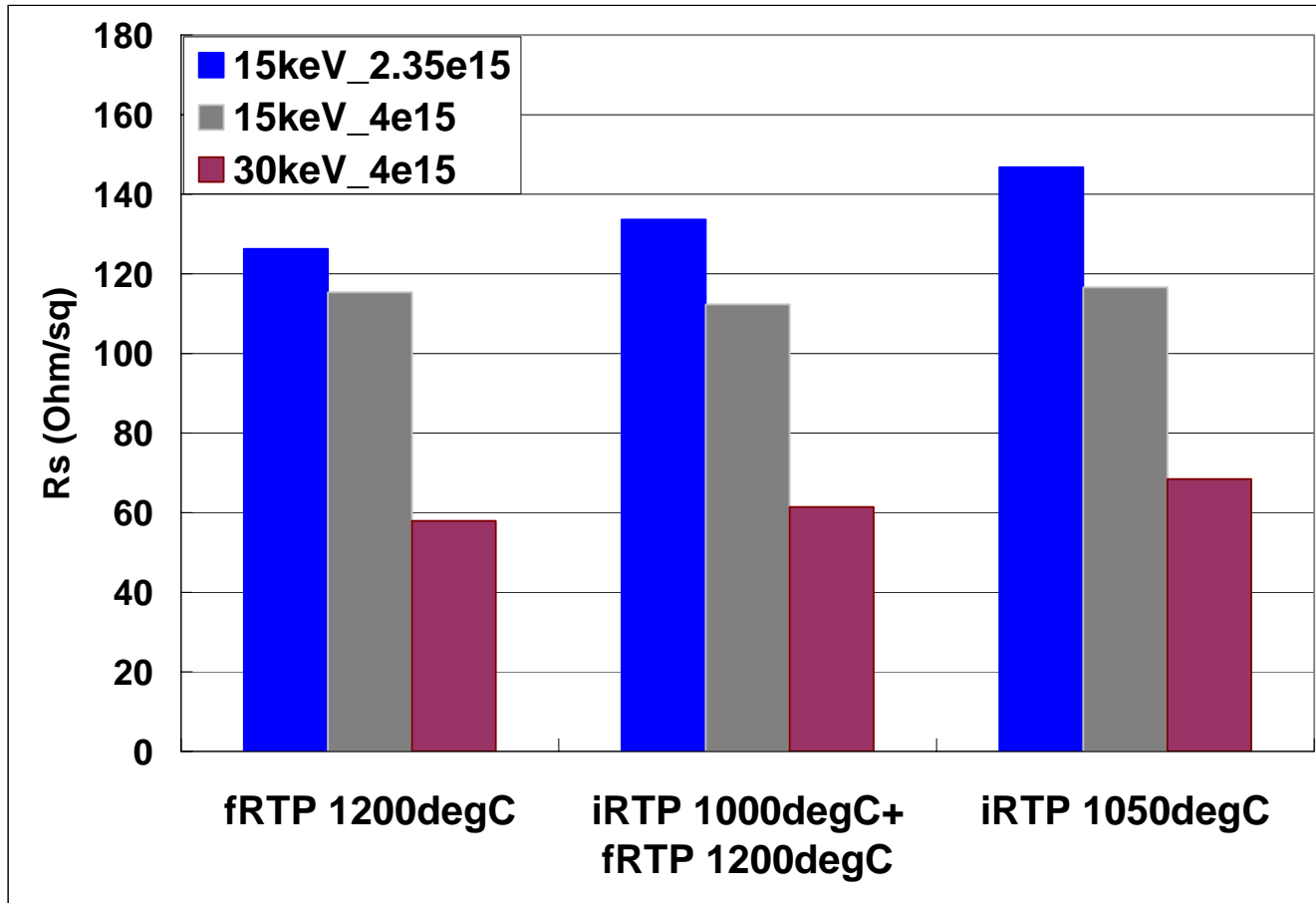
#	Sample	Phos Energy	Phos Dose (atoms/cm ²)	Laser 550 mJ/cm ²	Flash 1200°C	iRTP 1000°C + fRTP 1200°C	iRTP 1050°C	Soak 1000°C, 5sec
1	(P+C ₇)	15keV	2.36E+15	140	126	134	147	128
2	(P+C ₇)	30keV	4.00E+15	116	58	61	68	93

No drastic variation in Rs values of Phos energy and dose at different anneal conditions

P + C₇H₇

Rs

15keV & 30keV

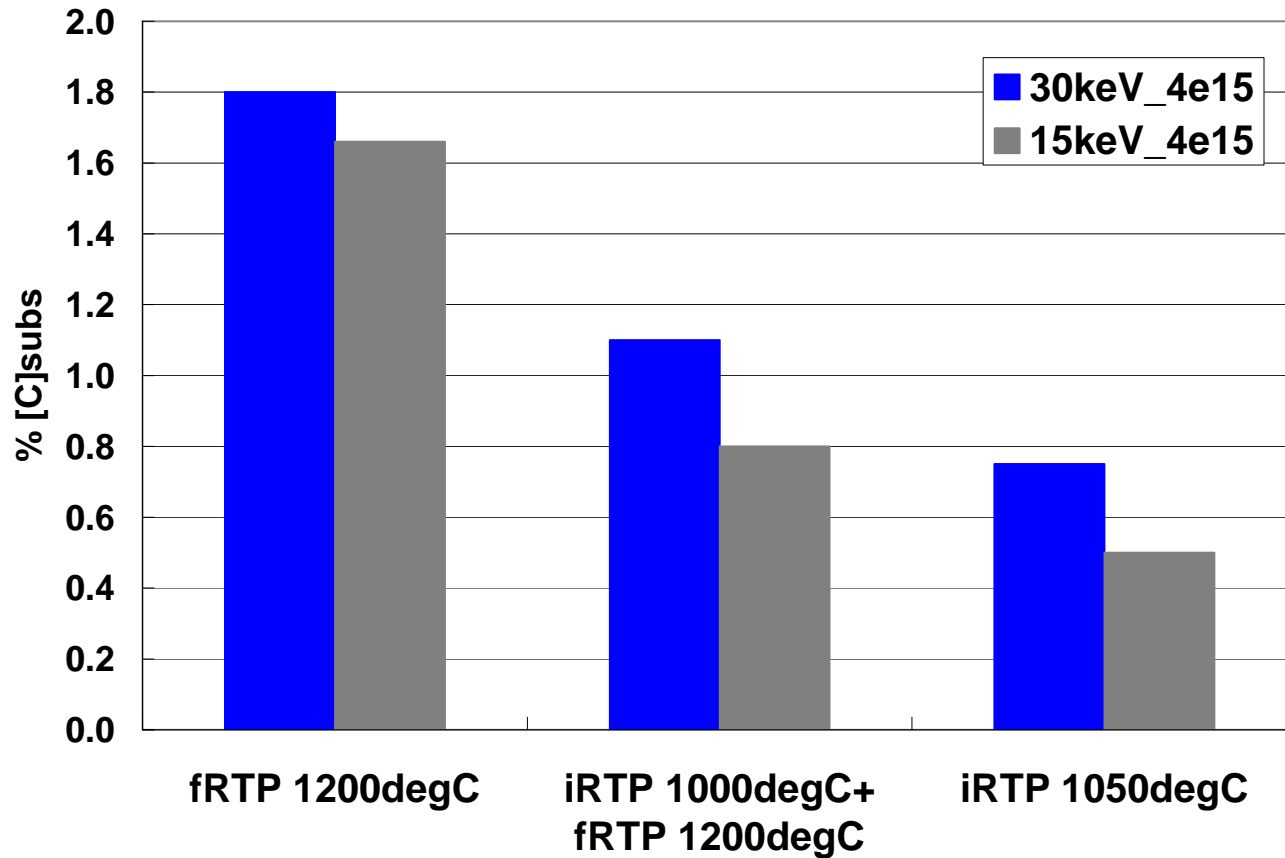


Low Rs : Deeper Phos implants & higher Phos dose (at same energy)

P + C₇H₇

[C]_{subs}

15keV & 30keV_4e15

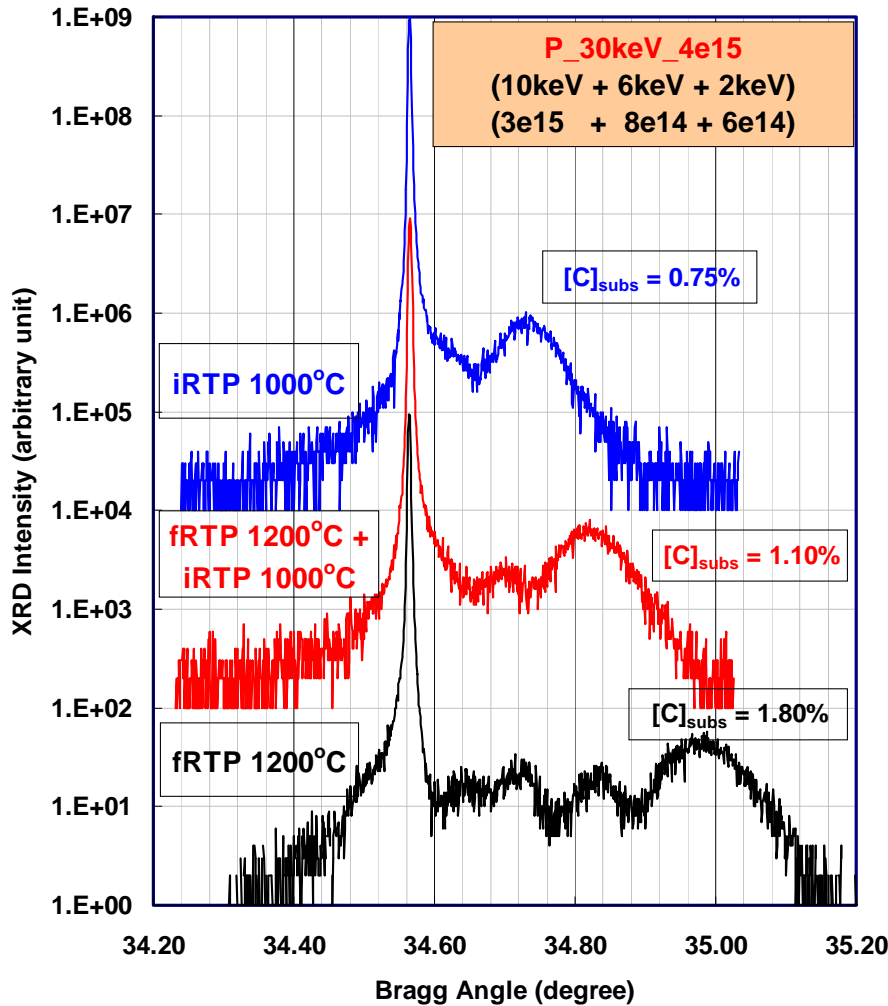


The % of [C]_{subs} is higher for higher energy Phos – less number of competing Phos atoms

HRXRD – FLASH ANEAL

P + C₇H₇

30keV_4e15

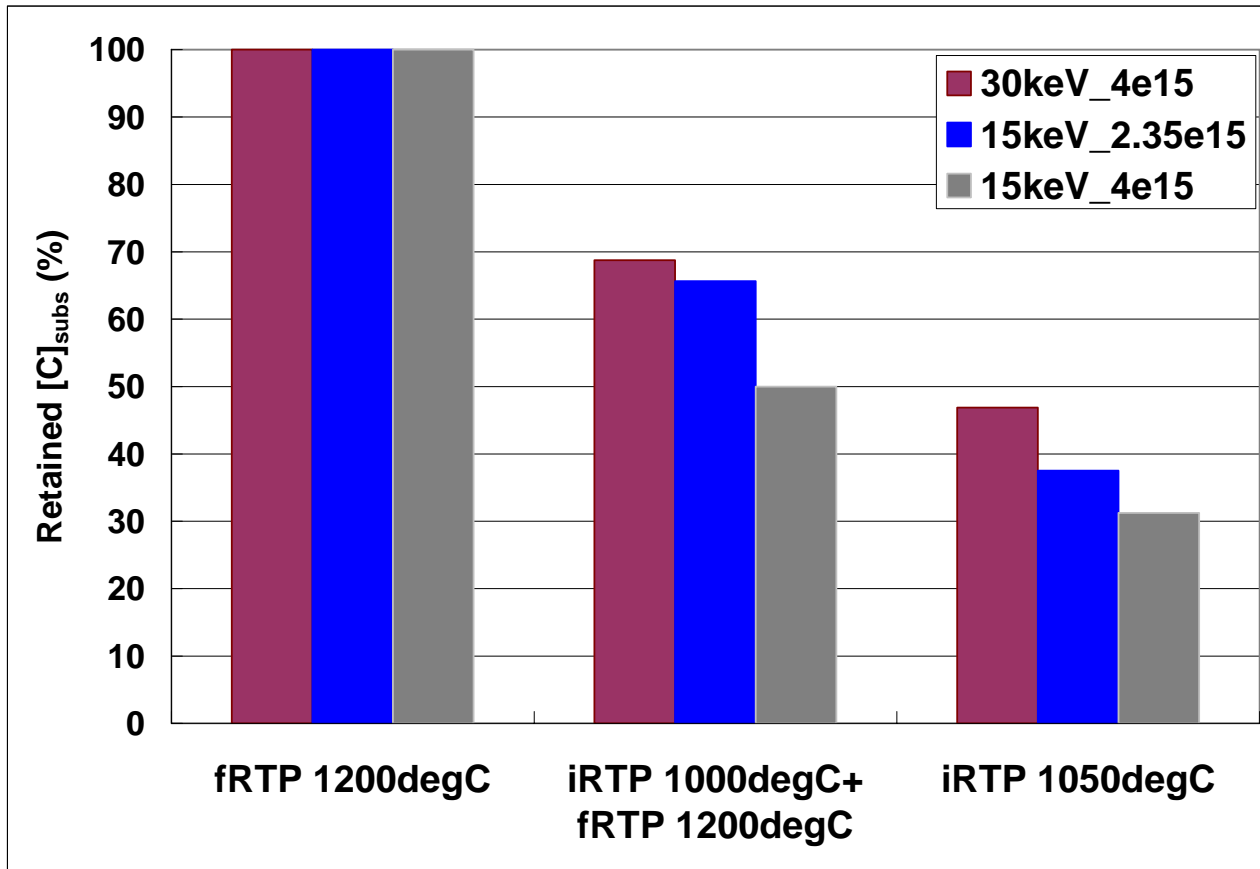


Retained [C]_{subs} drops down with spike anneals.

P + C₇H₇

Retained [C]_{subs}

15keV & 30keV_4e15

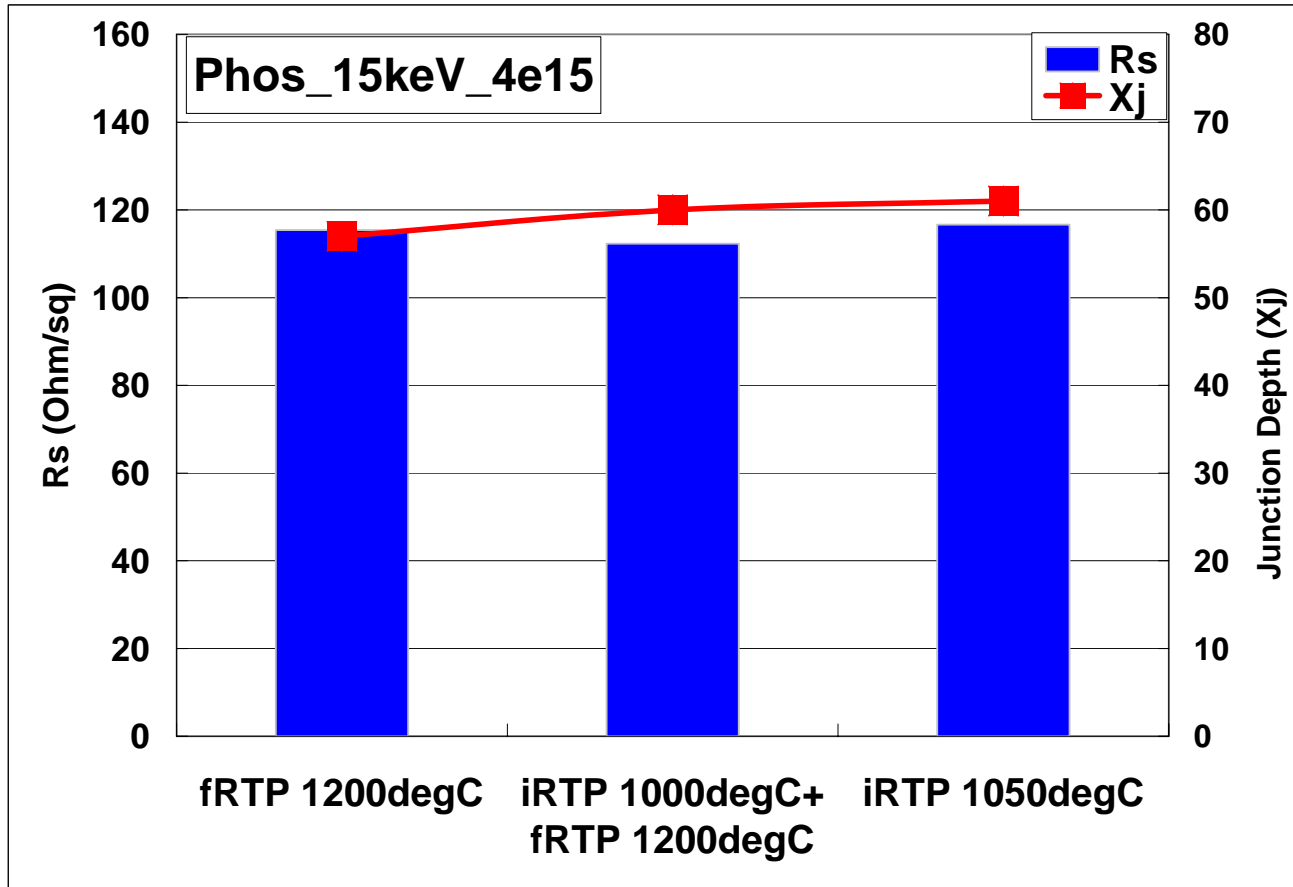


Larger retention % of [C]_{subs} for higher energy Phos – less number of competing Phos atoms.

At same energy, higher Phos dose kicks out more carbon leading to lower retention.

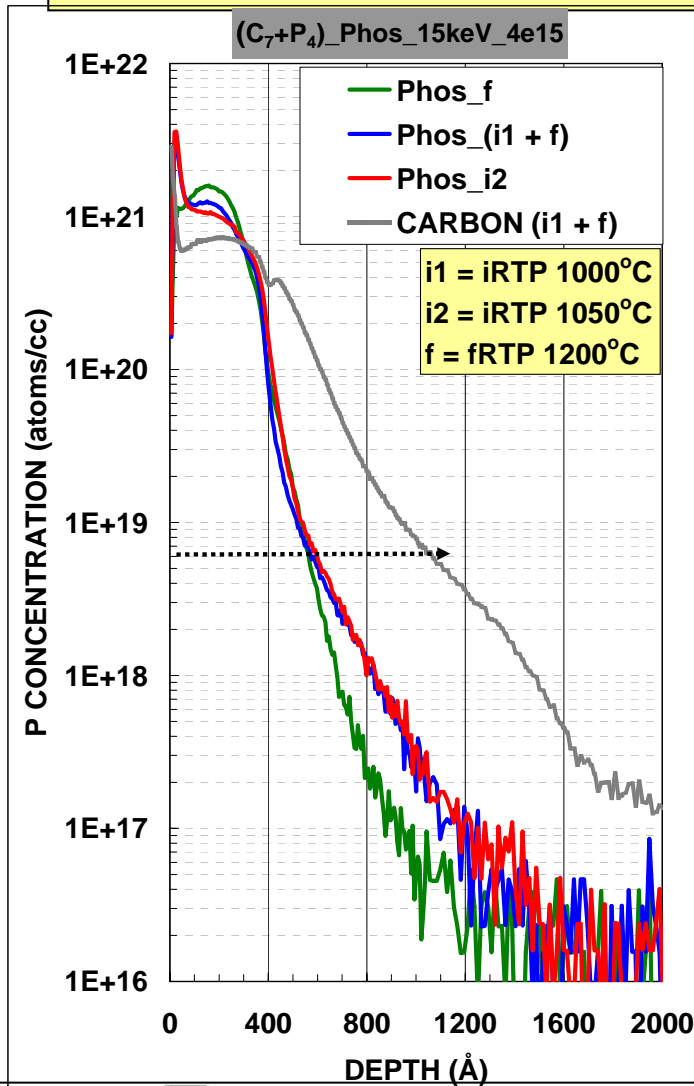
P + C₇H₇
Rs & Xj

15keV_4e15



Rs and Xj did not change much under various anneal conditions.

SIMS profile : (C₇ + P) – Phos 15keV, 4e15 - annealed



No drastic change in X_j with different anneal conditions \Rightarrow C₇ acts as a diffusion barrier

Significant diffusion with spike anneal below 5×10^{18} atoms/cm³ \Rightarrow Junction depth is deeper than the amorphous layer thickness

Summary : Cluster Carbon for strain engineering

- ClusterCarbon at moderate doses produces NMOS stressor layers while preserving high quality phosphorus junction
- Optimized conditions : $[C]_{\text{atomic}} \sim 1.50\%$
 - Medium dose ($3.0 - 5.0 \times 10^{15}$) for dopants
 - trade off between low Rs and higher strain
- Complete recrystallization for 1.5 atomic percent carbon with n-type dopant implant.
- Higher $[C]_{\text{subs}}$ with msec anneal
- Reduction in strain retention with spike anneal